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A Variant for Using Regression Analysis to Assess the Electromagnetic Environment in an Urban Area

Dimcho Pulov
Department of Mechanical and Precision Engineering
Technical University of Gabrovo
Gabrovo, Bulgaria
pulov@mail.bg

Tsanko Karadzhov
Department of Mechanical and Precision Engineering
Technical University of Gabrovo
Gabrovo, Bulgaria
karadjov_s@abv.bg

Yuliya Pulova-Ganeva
Department of Organization and Methods of Social Activities
St. Cyril and St. Methodius University
Veliko Tarnovo, Bulgaria
jpulova@abv.bg

Abstract. **The current study was conducted by making a series of experimental measurements of the electric field strength *E*. The obtained results have been interpreted using the method of mathematical modelling because the object of study – electromagnetic environment (EME) is a multifactorial system. With the accepted limitation of considering the influence of only two factors (frequency and time intervals) a two-factor regression analysis was used. The processing of the obtained data was performed by two-dimensional quadratic objective function.**

Keywords: electromagnetic environment, electric field strength, regression analysis, two-dimensional quadratic objective function.

INTRODUCTION

The dramatic increase in the level of electromagnetic emissions in highly urbanized areas is due to the rapid development of radio communication technologies, which has resulted in an increase in the number of radio-electronic and communication equipment. These processes have a strong impact on various aspects of our daily lives, and have become one of the essential factors characterizing the environment. On the one hand, the electromagnetic radiation of anthropogenic origin above certain intensity levels is biologically active and can cause a number of harmful effects on human health. These issues are most clearly characterized by the concept of radio-wave ecology (environmental impact of television and radio broadcast) [1] - [5]. On the other hand an uncontrolled increase in electromagnetic emissions results in an increase in background noise, which above a certain level can deteriorate the quality of connections and even make parts of the frequency spectrum unusable. This is the problem of electromagnetic compatibility [6] - [8]. These two problems have been the subject of numerous scientific studies. The reason for this is the fact that the electromagnetic environment (EME) is always specific. It is necessary to carry out systematic investigations of the intensity and distribution of electromagnetic radiations under various environmental factors. This implies the study of EME created by various telecommunications equipment, vehicles, power grids, medical equipment, household appliances, etc. in a specific location, frequency range and time-interval.

Object of the current study is the electromagnetic environment (EME) in the area of the city of Veliko Tarnovo, Bulgaria. As we know, the electromagnetic field is characterized by three mutually perpendicular vectors – electric field strength *E*, magnetic field strength *H*, and power flow density of an electromagnetic field (Poynting vector) *S*. The energy of the electromagnetic field can be characterized by using one of the vectors. In real conditions, the conditions of electromagnetic field propagation can be influenced. Then, the energies of *E* and *H* are not equal. Therefore, the component that would characterize the field most completely is measured.

EXPOSITION

A. Measurement requirements in urban areas

The measurements in this study were carried out in the frequency range (1÷100) *MHz*. International Special Committeee on Radio Interference (CISPR) has developed recommendations and standards for measurement of

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parameters of electromagnetic fields in this frequency range, as follows:

– for frequencies $(30\ kHz \div 30\ MHz)$ H and E can be measured. When measuring H, a circular or square antenna up to *0,6 m* is used. A vertical rod antenna of length *1 m* is used when measuring *E*.

–for frequencies $(30 \div 300)\ MHz$ E is measured using $\lambda/_2$ horizontal vibrator.

A selective voltmeter SMV-11 (FMA-11 antenna system) and a selective micro voltmeter SMV- 8, 5 (DP-1 antenna system) were used as meters. They are graduated in decibels relative to1 μV .

The measurements are compliant with CISPR recommendations regarding the influence of the environment, such as trees, buildings, the soil with its parameters (absolute permittivity ε and relative permittivity ε_r), the height of the antenna system, presence of objects commensurate in size with the wavelength λ of the measured signals. The measurements were made at randomly selected sites, therefore a schedule of distribution of levels and averaging of the results was drawn up. For frequencies up to $100\ MHz$ there is a linear variation of the electric field strength with height variation. For this reason, the measurements were performed with the antenna raised to a height of $(4 \div 10)\ m$, which corresponds to the CISPR recommendation for measurements in urban areas.

In urban areas EME is complex and is a combination of external and internal EME. In this particular case the study focuses on obtaining and processing large arrays of measured values of electric field strength *E* [5], [7], [8]. They determine the external electromagnetic environment with respect to the radio-electronic devices located near the point of measurement. Obviously, the analysis of the electromagnetic environment is complicated by multiple factors.

The internal EME is determined by the electromagnetic radiation (background) of industrial equipment, radio-electronic devices, high current devices, motors, fluorescent lamps, high voltage transmission lines, as well as by the mutual interference caused by operating radio-electronic devices located nearby each other. The internal electromagnetic environment is related to the nearby zone (induction zone) and has a very complex character, manifested as interfering radio emissions or interfering voltages on power lines and objects. The internal EME which results from mutual interference is of special scientific interest related to the operation of complex radio-electronic systems (ships, aircraft, radio-electronic equipment with defence and security applications) and requires research in each specific case.

B. *Experimental arrangement*

The experimental arrangement is shown in fig. 1. The input of the meter receives a set of "n" radiation sources which are randomly located in time, space and frequency with different energy and spatial characteristics and parameters of the antenna—feeder devices.

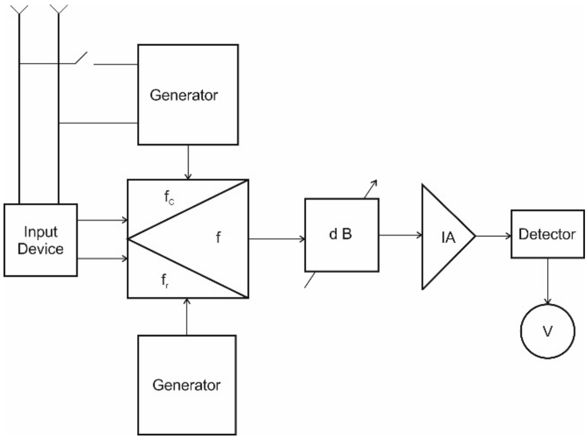

Fig. 1. Experimental system.

The meter converts the space of received signals into a space of measurement results. Fig. 2 shows the functional block diagram of the measurement system. It consists of an input device (antenna system), a receiving amplifier and a recording device. It can be assumed that all interferences (internal and external) are at the input of the meter [9], [10].

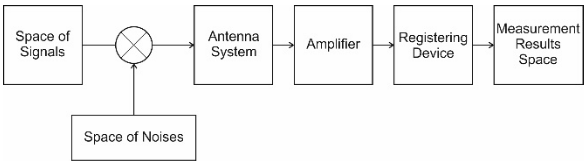

Fig. 2. Functional block diagram of the measurement system.

C. *Methodology of the study*

There are 4 sub-ranges in the frequency range $(1 \div 100)\ MHz$:

- $f^I = (1{,}5 \div 5)\ MHz$,
- $f^{II} = (5 \div 10)\ MHz$,
- $f^{III} = (10 \div 20)\ MHz$,
- $f^{IV} = (30 \div 100)\ MHz$.

Measurements of the sites at selected points were performed for these sub-ranges and other measurements were made in an anechoic chamber.

One 24 hour cycle is divided into 10 time-intervals $(t_1, t_2, \dots t_{10})$ according to table 1. For each interval measurements were made sequentially for all frequencies $(1 \div 100)\ MHz$ at three selected points and five points in the vicinity, meeting the requirement for relative accuracy of the measurement.

The multi-factor conditioned electric field strength can be generally represented by the function

$$E = \varphi(P, G, D, f, A) \quad dB\left[{}^{\mu V}/_{m}\right] \qquad (1)$$

where: P – power of the far emitter; G – coefficient of directional action of the antenna-feeder device; D – gain factor of the antenna feeder device; f – frequency of the far emitter; A – a parameter defining the conditions for electromagnetic field propagation.

TABLE 1 TIME-INTERVALS FOR MEASURING THE ELECTRIC FIELD STRENGTH

Time-intervals		Time-intervals	
t_1	$(00^{00} \div 02^{24})\ h$	t_6	$(12^{00} \div 14^{24})\ h$
t_2	$(02^{24} \div 04^{48})\ h$	t_7	$(14^{24} \div 16^{48})\ h$
t_3	$(04^{48} \div 07^{12})\ h$	t_8	$(16^{48} \div 19^{12})\ h$
t_4	$(07^{12} \div 09^{36})\ h$	t_9	$(19^{12} \div 21^{36})\ h$
t_5	$(09^{36} \div 12^{00})\ h$	t_{10}	$(21^{36} \div 00^{00})\ h$

Dependence of E on the frequency f and the time-intervals $(t_1, t_2, \dots t_{10})$ is assumed because a significant part of the arguments in 1 are with unknown distribution laws. Therefore, E can be represented as a sum of random vectors in the vector space.

$$\|\vec{E}\| = \left\| \begin{matrix} \overrightarrow{E_{11}} & \overrightarrow{E_{12}} \dots \overrightarrow{E_{110}} \\ \overrightarrow{E_{21}} & \overrightarrow{E_{22}} \dots \overrightarrow{E_{210}} \\ \dots & \dots \dots \dots \\ \overrightarrow{E_{91}} & \overrightarrow{E_{91}} \dots \overrightarrow{E_{910}} \end{matrix} \right\| \quad (2)$$

In (2) the columns correspond to the time-intervals and the rows correspond to the seasonal measurements, as follows: $\overrightarrow{E_{81}}\ \overrightarrow{E_{82}} \dots \overrightarrow{E_{810}}$ – for the winter $\overrightarrow{E_{91}}\ \overrightarrow{E_{92}} \dots \overrightarrow{E_{910}}$, $\overrightarrow{E_{11}}\ \overrightarrow{E_{12}} \dots \overrightarrow{E_{110}}$ and $\overrightarrow{E_{21}}\ \overrightarrow{E_{22}} \dots \overrightarrow{E_{210}}$ – for the spring; the other rows are for the summer. The vector space in expression (2) can be considered uniform and the environment in which it exists – linear [8], [11].

D. Mathematical model

[12] - [15] shows that it is possible to use various approximation functions to model the dependence of the electromagnetic field on various factors. In the current study only the influence of the frequency f and the time-intervals $(t_1, t_2, \dots t_{10})$were taken into account. A model of polynomial type has been adopted as an appropriate model to study the electromagnetic environment. We switched to a two-factor regression analysis where the processing of the experimental data was performed using a two-dimensional quadratic function of the form

$$y = b_0 + b_1 x_1 + b_2 x_2 + b_{11} x_1^2 +$$
$$+ b_{22} x_2^2 + b_{12} x_1 x_2 \quad (3)$$

where: y – output value (electric field strength E in dB); x_1 - frequency f; x_2 – time-interval; x_1 and x_2 – values of the factors influencing the process; $b_0, b_1 \dots b_{12}$ – regression coefficients.

The vector of regression coefficients is determined by the matrix equation

$$[b] = \|[X]^T [X]\|^{-1} \cdot \|[X]^T [Y]\|$$

where: $[X]$ – input matrix corresponding to the regression form of the model; $[X]^T$ – transposed matrix.

The statistical study presented the primary model of the generalized electromagnetic environment. The generalized model of the electromagnetic environment defines the external EME for radio-electronic devices operating at the point of measurement and is the electromagnetic background interference for them [2], [12], [16]. The goal is to minimize the influence of this electromagnetic background interference and to find for which frequencies and time-intervals the minimum of the function y (electric field strength E) can be obtained.

A computer program was developed to calculate the regression coefficients (table 2).

Then, the model from expression (3) is transformed into the form

$$y = 14{,}2 + 1{,}25 x_1 + 1{,}13 x_2 + 6{,}19 x_1^2 +$$
$$+ 0{,}59 x_2^2 + 1{,}55 x_1 x_2 \quad (4)$$

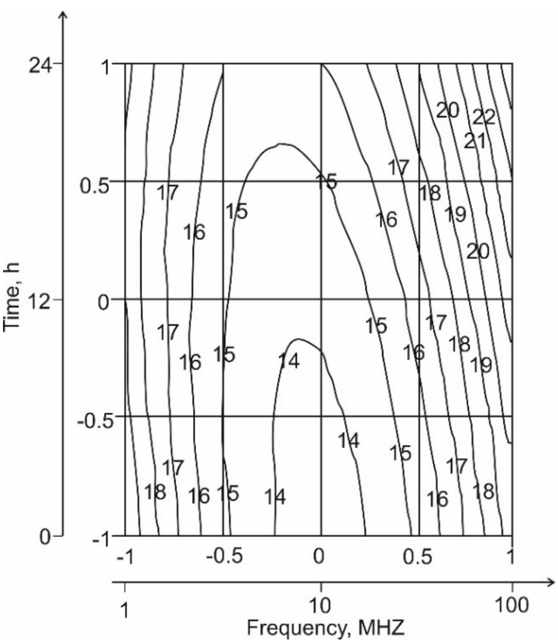

Fig. 3. Graphical results.

TABLE 2 REGRESSION COEFFICIENTS

Regression coefficients	
b_0	14,20057578
b_1	1,250516653
b_2	1,138633251
b_{11}	6,190785408
b_{22}	0,597690761
b_{12}	1,557432413

Expression (4) represents the mathematical model of the electromagnetic environment of the herein studied urban area in Veliko Tarnovo city, Bulgaria. The graphical interpretation of (4) is shown in fig. 3.

III. CONCLUSION

The conducted study of the electromagnetic environment in the city of Veliko Tarnovo, Bulgaria allows us to draw the following conclusions:

- Examination of model (4) shows that the function y (the electric field strength E) is influenced by x_1 (frequency f) and x_2 (time − interval), the fifth element being very small and the sixth element giving the correlation between x_1 and x_2. All regression coefficients are significant. The verification of the solution was limited to the numerical algorithm.

- Significant values of E at the points of measurement have been recorded in the time-intervals $t_1, t_2, t_5, t_6, t_9, t_{10}$.

- Levels of E in different frequency ranges have been registered as follows:

f^I – до 35 dB; f^{II}– $(35 \div 40)\ dB$;

f^{III}– $(35 \div 45) dB$; f^{IV}– $(18 \div 54)\ dB$.

The industrial interference levels are significant in value and it is therefore imperative to make engineering calculations on a case-by-case basis regarding shielding, grounding, filtration and appropriate placement of radio-electronic equipment. As the distance from the emitting object increases $(10 \div 20)\ m$ the field intensity decreases.

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